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(54) Portable Alkaline Fuel Cell with on Board Hydrogen Supply

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APSTRACT

A portable power supply having an alkaline fuel cell and on-board hydrogen storage. As required, hydrogen is released from the storage media which may be a metal hydride and along with a supply of oxygen, the fuel cell produces current when under load. The hydrogen supply to the fuel cell vaporizes water produced at the anode where the hydrogen/water vapor stream is recycled to the metal hydride storage system to release additional hydrogen for circulation to the fuel cell. On-board water storage and water drainage from the fuel cell is thereby eliminated in this portable system.

PORTABLE ALKALINE FUEL CELL WITH ON BOARD HYDROGEN SUPPLY

FIELD OF THE INVENTION

This invention relates to a power supply and more particularly an alkaline fuel cell for producing electrical power which requires in its operation sources of hydrogen and oxygen.

BACKGROUND OF THE INVENTION

Fuel cells have been commonly constructed to produce electrical energy as derived from the free energy of chemical reaction at the anode and cathode of the fuel cell. Fuel cells may have either an acidic electrolyte or an alkaline electrolyte. For either fuel cell type, hydrogen is circulated over the anode and oxygen is circulated over the cathode to produce electrical power. In the alkaline fuel cell, the oxidation of hydrogen at the anode produces water with a flow of electrons to the cathode to reduce oxygen. Such operation of fuel cells is well understood by those skilled in the art in view of the technology having been available since at least the early 1900s. A representative alkaline fuel cell is described in United States patent 3,132,973. The invention described in this patent is directed to a low temperature fuel cell. During its operation water vapor is produced at the hydrogen electrode or anode. Provision is made to drain the water as produced in the fuel cell by way of an external drain cock in the enclosure of the fuel cell. With this type of fuel cell, external sources of oxygen and hydrogen are provided where it is understood that the hydrogen and oxygen are free of carbon dioxide to avoid the formation of carbonates in the fuel cell, which long term can reduce the efficiency of the cell. The oxygen may be derived from air which has been treated to provide an oxygen enriched stream with the carbon dioxide removed. The hydrogen may be from a suitable source such as

compressed gas in a cylinder or as derived from hydrolysis of water.

The generally accepted difficulty, however, with fuel cells and the required hydrogen for purposes of operation has been the development of a high performance fuel cell which is of economical design. Furthermore, for purposes of portability the need for a hydrogen storage system that is lightweight, economical and can be integrated with the fuel cell so that hydrogen is supplied to the fuel cell as required during operation.

Wallace et al, *Int. J. Hydrogen in Energy*, Vol 8, No. 4, pp 255-268, 1983, "Hydrogen as a Fuel", discuss several considerations in the storage of hydrogen and its use as a source of energy. In this paper, consideration is given to the storage of hydrogen as a cryogenic liquid, a metal hydride or as ammonia to provide carbon-free hydrogen to a fuel cell. Hydrogen, as stored in one of the above forms, may then be used to power the fuel cell where the necessary oxygen for the alkaline fuel cell can be obtained from air. As discussed the air may be treated with a suitable absorption system to remove carbon dioxide from the air so as not to pollute the fuel cell.

Taschek et al, "High Energy Metal Hydride Fuel Cell Power Source", *US Army Mobility Equipment Research and Development Command*, Fort Belvoir, Virginia, (1979) disclose a high energy metal hydride fuel cell. The fuel cell has an acidic electrolyte where oxygen uptake at the cathode produces water at the cathode. The oxygen may be derived from air. As to the hydrogen, it may be derived from liquid fuel such as methanol. As noted in this paper, the concentration of carbon monoxide in the hydrogen and oxygen streams must be kept low, that is less than 3%. Furthermore, it is thought that with alkaline electrolytic fuel cells, pure oxygen and hydrogen are desired to avoid reaction of carbon dioxide in air and any reformed fuel streams which are a source of hydrogen,

with the electrolyte of the fuel cell. A fuel cell having a solid polymer electrolyte is also described. Water formed in the fuel cell simply drips off of the solid electrolyte and hence may be drained away. As noted with liquid electrolyte fuel cells, water is picked up by the electrolyte which is undesirable and hence the water must be removed; for example in the manner taught in the aforementioned United States patent 3,132,973. As described in this paper, hydrogen may be derived from calcium hydride which supplies hydrogen on demand by the fuel cell. A water reservoir is provided where water flows from the reservoir into the water chamber adjacent to a porous hydrophobic membrane in the container for the calcium hydride. Water vapor diffuses through the membrane and spontaneously reacts with the calcium hydride to release hydrogen. The hydrogen then escapes the container of calcium hydride and is directed to the anode of the fuel cell. Control in the production of hydrogen is provided by virtue of water being forced back into the water reservoir during no load, because hydrogen is not consumed at the anode of the fuel cell. As hydrogen is consumed by the fuel cell during load, the water level will self-adjust to generate only the required amount of hydrogen. With this type of hydrogen generation, it is recommended that the fuel cell be of the solid polymer electrolyte, because of its ability to operate at low temperatures.

A compact portable form of fuel cell having portable hydrogen generation is disclosed in Design News, December 5, 1988. The fuel cell and hydrogen generator are sufficiently compact to fit in a large size briefcase with a weight in the range of 25 pounds. The oxygen supply may be taken from air. The hydrogen supply is in the form of physically bonding of hydrogen to a metal compound to form the metal hydride. Gentle heating of the metal hydride releases hydrogen gas under pressure to supply hydrogen gas at the anode. Intermittent purging

of the fuel cell is required to remove the produced water so as to not dilute the electrolyte. For the unit disclosed in the article, the electrolyte is acidic so that water is produced at the cathode.

There continues, however, to be a need for a lightweight portable fuel cell with on-board hydrogen generation which is economical and can effectively operate over a broad range of temperatures.

SUMMARY OF THE INVENTION

Accordingly, an aspect of the invention is embodied in a power supply having:

a) an alkaline fuel cell,

b) a hydrogen storage system,

c) means for pumping released hydrogen from an outlet of said hydrogen storage system to a hydrogen inlet for said fuel cell,

d) a source of oxygen,

e) means for pumping oxygen from said oxygen source to an oxygen inlet for said fuel cell, and the improvement comprising:

i) said hydrogen storage system including a solid chemical hydride for storing hydrogen in a chemically bound form, said chemical hydride releasing hydrogen gas when contacted by and reacted with water molecules, said storage system having an outlet connected to said hydrogen pumping means; and

ii) said fuel cell having said hydrogen inlet connected to said hydrogen pumping means and an outlet for exhausting excess hydrogen from said fuel cell, means for passing hydrogen from said fuel cell hydrogen inlet over said anode to react at said anode and vaporize water produced at said anode during operation of said power supply to form thereby a hydrogen/water vapor mixture exhausted at said fuel cell outlet, means for recirculating exhausted hydrogen/water vapor mixture from said fuel cell outlet to an inlet of said hydrogen

storage system to reintroduce thereby water molecules to said chemical hydride to release additional hydrogen gas at said outlet of said hydrogen storage system.

According to another aspect of the invention, a hydrogen storage system for use in a portable power supply using an alkaline fuel cell which requires hydrogen for power generation comprises:

i) a container having an inlet and an outlet, each with means for releasable connection to hydrogen transport tubing,

ii) a granular solid chemical hydride for storing hydrogen in a chemically bound form, said hydride being stored in said container with a water vapor membrane isolating said chemical hydride from said inlet; and

iii) said container inlet directing hydrogen and entrained water vapor through said granular hydride to produce hydrogen which is exhausted through said outlet.

According to a further aspect of the invention, a process for generating power in an alkaline fuel cell which requires hydrogen at its anode and oxygen at its cathode during power generation comprises:

i) storing hydrogen in a chemically bound form as a solid granular chemical hydride, said chemical hydride releasing hydrogen when contacted by and reacted with water molecules,

ii) pumping released hydrogen from said storage to said fuel cell and passing hydrogen over said anode of said fuel cell to develop power when oxygen is present at said cathode where water vapor is produced at said anode during power generation,

iii) an excess of hydrogen being pumped through said fuel cell as generated by reaction of water molecules with said hydride, said water vapor in said cell vaporizing in said flow of hydrogen to form a hydrogen/water vapor mixture;

iv) recirculating said hydrogen/water vapor mixture to said hydrogen storage whereby water molecules of said water vapor reacts with said hydride to release more hydrogen which is pumped to said fuel cell;

v) during power demand, said hydrogen/water vapor mixture being continuously recirculated whereby all water vapor produced at said anode is recirculated and reacted with said chemical hydride to maintain a steady state operation of a cycle of hydrogen release, hydrogen consumption at said fuel cell anode and production of water vapor at said fuel cell anode for further generation of hydrogen.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are shown in the drawings wherein:

Figure 1 is a schematic section through a preferred embodiment for the portable power supply of this invention; and

Figure 2 is a schematic of the hydrogen storage system and its connection to the fuel cell.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The power supply, according to a preferred embodiment of this invention, is designed to provide power over an extended period while operating at temperatures ranging from -40°C to +40°C. Preferably the power supply is portable with a weight in the range of 5 kg or less. Preferably the system is mechanically rechargeable which, in accordance with alkaline fuel cells, requires the replacement of the source of hydrogen. According to the various embodiments of this invention, the preferred source of hydrogen is in the form of a chemical hydride storage system which upon contact with and reaction with the water molecules, releases hydrogen for use at the anode of the fuel cell. Due to the preferred portable nature for the power supply, the source of oxygen required at the cathode of the fuel cell is derived from air. The power supply is

preferably housed in an enclosure particularly when the supply is to be portable. The enclosure may be opened to access and replace hydrogen storage canisters to service the system and provide for start-up of the system.

A unique property of the alkaline electrolyte fuel cell is that water molecules, usually in the form of water vapor, are produced at the hydrogen electrode or anode of the fuel cell. The reactions which take place in the fuel cell are as follows:

AT THE ANODE

$$4H_2 + 8OH^- \Rightarrow 8H_2O + 8e^-$$

and

AT THE CATHODE

$$2O_2 + 4H_2O + 8e^- \Rightarrow 8OH^-$$

Electrons then flow from the anode to the cathode through an external circuit to supply the necessary electrons at the cathode for conversion of oxygen to the hydroxyl groups. In the production of the electrons at the anode due to the reaction of hydrogen with the hydroxyl groups, water is produced. However, not all of the water produced at the anode is required at the cathode to convert the oxygen to the hydroxyl groups. As described with reference to the prior art, this produced water is normally discharged from the system in one manner or another so as not to further dilute the electrolyte. However according to this invention, it has been found that, as the hydrogen flows over the anode, the water or moisture produced at the anode may be vaporized by the warm or hot hydrogen stream to provide a moist hydrogen stream or hydrogen/water vapor stream. According to this invention, rather than the conventional approach of discharging such hydrogen water/vapor stream to the atmosphere, the stream is used internally of the system to facilitate continued production of hydrogen.

According to this invention, the hydrogen is stored in the form of a chemical bond of hydrogen to metals

which form metal hydrides. The hydrogen is released by chemical reaction with the metal hydrides where, according to this invention, such reaction is carried out with water molecules. For example with calcium hydride or lithium aluminum hydride, upon contact with water molecules, release hydrogen. Calcium hydride as the chosen granular storage medium, the reaction proceeds as follows:

$$2CaH_2 + 4H_2O \Rightarrow 2Ca(OH)_2 + 4H_2$$

With the hydrogen storage medium being lithium aluminum hydride, the reaction is as follows in the production of hydrogen:

$$LiAlH_4 + 4H_2O \Rightarrow Li(OH) + Al(OH)_3 + 4H_2$$

Although calcium hydride and lithium aluminum hydride are preferred forms of chemically bound metal hydrides, it is understood that there are a variety of other types of metal hydrides which are useful in this invention, such as $LiBH_4$, $NaBH_4$, KBH_4, $NaAlH_4$, LiH, NaH and MgH_2 and like alkali or alkaline earth metal complexes. Also, LiH or NaH in the presence of Al; Si or Al in the presence of NaOh and Ca with excess water.

According to this invention, the recirculation of the hydrogen/water vapor stream taken from the fuel cell and recirculated through the metal hydride storage system results in the water vapor in the hydrogen stream generating additional hydrogen. The net reaction for the fuel cell in the hydrogen storage system, when calcium hydride is used as the hydrogen storage system, is as follows:

$$2CaH_2 + 2O_2 \Rightarrow 2Ca(OH)_2 + 214.2 \text{ Amp Hr.}$$

Similarly when the storage medium is lithium aluminum hydride, the net reaction for the fuel cell and hydride storage system is as follows:

$$LiAlH_4 + 2O_2 \Rightarrow Li(OH) + Al(OH)_3 + 214.2 \text{ Amp Hr.}$$

The design of the hydrogen storage system is such that all the moisture pick-up at the anode in the passage

of the hydrogen stream through the fuel cell reacts with the chemical hydride to produce additional hydrogen. As the hydrogen stream is circulated back to the fuel cell, a steady state for the system operation is achieved because the necessary amount of water to regenerate hydrogen for continued operation of the power supply is supplied at the anode of the fuel cell. Hence the water produced by the fuel cell at the anode is completely used in the hydrogen storage system. As a result, no water need leave this system which is contrary to the prior art devices which provide for draining of water from the fuel cell. As a result, the water required for continued operation of the fuel cell is always within the enclosure which may be insulated. This is particularly important for the system when operating under extreme environmental conditions, such as -40°C or as high as 40°C.

Figures 1 and 2 schematically show preferred embodiments of the invention for the portable power supply using the alkaline electrolyte fuel cell. The portable power supply 10 is housed in an enclosure 12 having a removable access door 14 secured to the enclosure by releasable clips 16. Externally of the enclosure 12 are the positive and negative terminals 18 and 20 for the portable power supply.

The enclosure 12 may be insulated as required to maintain the necessary temperature within the portable system for efficient operation of the fuel cell and hydrogen generation from the hydrogen storage at the temperature extremes of -40°C. Ventilation ports 22 may be provided in the enclosure walls and the access door 14 to allow for cooling of the system during use, particularly for elevated temperatures which may be in the region of 40°C. Ventilation is established in the enclosure walls to provide for ventilation on each side of the internal partition 24 for the portable power supply. For reasons to be later discussed, the internal partition 24 may be movable in the directions of arrow 26

to either have the partition 24 in place as shown in Figure 1, or withdrawn from the enclosure to open up the space between the hydrogen storage system and the fuel cell.

Contained within the enclosure 12 are the two principal components. The hydrogen storage system 28 is on one side of the partition 24. The fuel cell 30 is located on the other side of the partition 24. The fuel cell is constructed in accordance with standard techniques involving use of an alkaline electrolyte preferably potassium hydroxide. Hydrogen is introduced to the fuel cell through inlet 32 to which is connected hydrogen line 34. Similarly oxygen, which may be in the form of treated air, is introduced to the fuel cell through inlet 36 to which is connected line 38. The oxygen, as it flows over the cathode, is exhausted from this fuel cell at outlet 40 to which is connected line 42 which exhausts the air out of the system externally of the enclosure through outlet 44. The hydrogen passes over the anode 46 and is exhausted from the fuel cell through outlet 48 to which is connected line 50. The fuel cell is supported on the bottom 52 of the enclosure by support stand 54.

Line 50 extends through the partition 24 if it is always stationary in the enclosure 12, or extends along the insulated sidewall in the event of desire to remove the partition from the enclosure. The line 50, as it extends into the chamber housing the hydrogen storage system, recirculates the hydrogen/water vapor from the outlet 48 of the fuel cell to the inlet 52 of the hydrogen storage system. The hydrogen stream, in accordance with this embodiment, travels through the start-up heater 55 and the valve block 56 before entry to the container 58 for the granular chemical hydride storage media. The container 28 is supported above the base of the enclosure by block 57.

Hydrogen, as generated in the container 58, is released through valve block 56 to the outlet 60 for the hydrogen storage system 28. A pump 62 pumps the hydrogen in line 64 from the outlet 60 of the hydrogen storage system through to line 54 to the inlet 32 of the fuel cell. The outlet of the pump 62, as connected to line 34, may either pass through the partition or beside it through the side wall. Similarly, air from outside the enclosure 12 is brought into the power supply system through line 66 which enters the pump 62 in line 68. Pump 62 pumps air through its outlet to line 70 which either extends through the partition or beside it. Line 70 leads to the inlet 72 of a carbon dioxide scrubber 74. The outlet 76 of the scrubber is connected to line 38 which, in turn, leads to inlet 36 for the fuel cell. The scrubber contains a suitable media to remove the carbon dioxide and other carbon oxides from the air so that the air as it exits the scrubber through outlet 76 is free of any carbon constituents and in particular carbon dioxide and carbon monoxide.

Although there are a variety of CO_2 absorbing systems, the preferred system for removing carbon dioxide from air is to pass the air through a bed of CaO (calcium oxide) granules or an aqueous solution containing CaO. The reaction for removing CO_2 is:

$$CaO + CO_2 \Rightarrow CaCO_3$$

The scrubber contains sufficient calcium oxide to remove the anticipated amount of carbon dioxide passing through the system for up to a 24 hour period. It has been estimated that approximately 7 grams of calcium oxide in the scrubber is more than adequate to handle the necessary removal of CO_2 from the air passing through the system. Preferably the scrubber 74 is in the form of a canister which has quick disconnect couplings at inlet 72 and outlet 76. The scrubber may then be replaced every 24 hours during use of the power supply.

The pump 62, according to this embodiment, is a double sided pump having pump units 78 and 80 driven by a single motor 82 having electrical terminals 84 and 86. The motor 82 of the pump is therefore connected to the power supply derived from the fuel cell 30. The motor is designed to draw very low power during its operation so as not to reduce significantly the output of the fuel cell at terminals 18 and 20. The pump should be capable of circulating in the range of 3.5 liters H_2/min. and 3.5 liters air/min. or higher flow rates as required. Such pumps usually operate at a voltage of 5 volts with a power draw of less than one watt.

The fuel cell 30 is, as mentioned, may be of a standard construction with the provision of oxygen at inlet 36 to flow over the cathode 37 and hydrogen at inlet 32 to flow over the anode 46 to generate electrical current at the terminals 18 and 20. The alkaline fuel cell having KOH as the electrolyte can achieve a current density of approximately 1 amp/cm^2 and a cell voltage of approximately 0.7 v. This type of fuel cell functions quite efficiently at low temperature and low pressure. By virtue of operation at lower temperatures and pressures, the enclosure 12 for the system, as well as the construction and interconnection of the fuel cell to the hydrogen storage is greatly simplified for purposes of providing a portable system. It is appreciated that the features of this invention may also be incorporated into a stationary system which is comparable in size to the portable unit or a considerably larger more powerful type of power supply.

The KOH electrolyte fuel cell provides for the reduction of oxygen and the oxidation of hydrogen at the KOH-catalyst interface. Suitable catalysts for enhancing the performance of the cell is platinum (Pt). To optimize the performance of the fuel cell, it has been found that the flow rates for the hydrogen and oxygen should be in excess of the theoretical consumption rates

for hydrogen and oxygen at the anode and cathode respectively. The pump 62 is designed to deliver flow rates in the range of 3.5 liters per minute of air and hydrogen which greatly exceeds the theoretical consumption rate. Depending upon the voltage required at terminals 18 and 20, a stack of fuel cells may be provided in series to develop the necessary voltage. A ten cell stack, which produces approximately 83.4 watts at 8.16 volts, requires in the range of 0.7 liters per minute of hydrogen during current production of 53.55 amp/hour. It is desired to use at least five times that theoretical consumption rate and hence at least the 3.5 liter per minute delivery rate for the pump 62.

With reference to Figure 2, the preferred set up for the hydrogen storage system 28 is schematically illustrated. The hydrogen storage system consists of two hydrogen storage canisters 88 and 90. The recirculated hydrogen and water vapor in line 50 is introduced to the hydrogen storage system 28 through inlet 52. Inlet 52 via line 92 leads to the start-up system 54. Start-up system 54 consists of a sub-container 94 of an aqueous solution and a sub-container 96 of a chemical hydride. The hydrogen/water vapor in line 92 travels through the start-up system 54 after it has been actuated and exits at outlet 98 for the start-up system and leads to valve 100. Valve 100 is part of the valve block 56. Valve 100 may be adjusted to direct the flow of hydrogen/water vapor through line 102 which is connected to outlet 60, or through line 104 which is connected to valve 106 of the valve block.

Valve 106 may be selectively moved to direct the hydrogen/water vapor stream through line 108 which leads to the inlet 110 of hydrogen storage container 90. Alternatively valve 106 may direct the hydrogen/water vapor stream through line 112 to the inlet 114 of hydrogen storage container 88. Valve 116, which is also part of the valve block 56, directs the flow of hydrogen

from either hydrogen storage containers 88 or 90. With valve 116 in a first position, hydrogen leaving the storage container 88 through outlet 118 flows through line 120 to valve 116. With the valve in a second position, hydrogen released from the second storage container 90 exits through outlet 122 through line 124 to valve 116. Valve 116 directs the flow of hydrogen through line 126 to the outlet 60.

At any time during the operation of the fuel cell, when hydrogen is being generated, the valves of the valve block are set as follows. Valve 100 directs the flow of hydrogen/water vapor through line 104. Valve 106 directs the flow of hydrogen to the first container of hydride 88. Valve 116 directs the flow of released hydrogen from outlet 118 through line 120 to line 126. The reaction of water molecules in the water vapor stream with the hydride in the canister 88 releases hydrogen and produces metal hydroxide. Preferably, the chemical metal hydride is a solid granular material which allows the hydrogen/water vapor to flow through the granular bed to release additional hydrogen.

As is understood with respect to chemical hydride storage systems, membranes are used in the canister so as to define a discrete volume of the hydride. The gas stream containing moisture can be pumped through the canister so that moisture reacts with the hydride to produce hydrogen at a controlled rate, where the rate is controlled by the presence of the membrane and the amount of moisture in the stream. When the hydride in canister 88 is spent, in order to continue the release of hydrogen, valve 106 is set to direct the flow of hydrogen and water vapor through line 108 to the inlet 110 of the canister 90. Valve 116 is set to direct the flow of released hydrogen from outlet 122 through line 24 to line 126.

Both canisters 88 and 90 at the respective inlets and outlets have quick disconnect/connect couplers 128

and 130. This permits replacement of the spent canister 88 with a fresh canister of metal hydride to continue production of hydrogen once the hydride in canister 90 is spent. At that point, the valving is adjusted to resume recovery of released hydrogen from canister 88. Canister 90 is then replaced with a fresh canister of hydride. The canisters have sufficient hydride to provide for approximately four to six hours of constant power generation from the fuel cell. Such generation times are readily achievable by use of lithium aluminum hydrides. Calcium hydrides are used and it has been found that the canisters need to be changed approximately every two hours. Canisters of either lithium aluminum hydride or calcium hydride are capable of delivering hydrogen at a rate of approximately 90 mls per minute and at a pressure of approximately 10 mmHg. For a stream consisting of hydrogen/water vapor to achieve a flow rate of 3.5 liters per minute of hydrogen, a larger canister of the hydride may be used.

Operation of the fuel cell in ambient temperatures in the range of 40°C does not cause a problem with this system and special cooling is not required. The temperature of the hydrogen stream, as it exits the hydride storage medium, is usually in the range of 150°C. The fuel cell functions properly at a temperature in the range of 80°C. Considering that at the higher ambient temperatures air brought into the system is in the range of 40°C, it has been found that cooling is not required providing sufficient ventilation is provided in the walls of the enclosure. Preferably hydrogen entering the fuel stack is cooled by extending its pathway before entry to the fuel cell. In this manner, the ambient at 40°C the fuel cell stack still operates at a steady state condition of 80°C.

Alternatively, operation of the system at -40°C is also possible. Firstly, the aqueous solution in the sub-container 94 must remain as a liquid at -40°C to permit

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start-up in the colder temperatures. Also the electrolyte for the fuel cell must be a liquid at -40°C and the fuel cell must be capable of delivering sufficient power to an external load at these lower temperatures. It has been found that the potassium hydroxide electrolyte for the alkaline fuel cell is a liquid at -40°C. The other consideration is the aqueous solution in sub-container 94 which, upon actuation of start-up valve 132, will release a liquid into the chemical hydride contained in the start-up sub-container 96. It has been found that a glycol water mixture of 46 vol. % water to ethylene glycol remains liquid at -45°C. With this water glycol mixture in sub-container 94, actuation of valve 132 dumps the liquid into the hydride of sub-container 96. This releases hydrogen from the sub-container even at the low temperatures of -40°C.

Valve 100 is positioned to direct the hydrogen through line 102 and out through outlet 60 to the fuel cell. The sub-container 96 develops sufficient pressure of hydrogen in line 102 that the hydrogen flows through the pump which is the type of pump which allows flow or is set to allow flow therethrough when not operating. Hydrogen then flows over the anode 46 in the fuel cell. Oxygen, which is present at the cathode 37, commences the reaction to generate power at terminals 18 and 20. The hydrogen, which continues to be generated in the sub-container 96, flows through the recirculation system back through any remaining aqueous solution in sub-container 94 and over the chemical hydride in container 96 to continue start-up of the fuel cells.

Once sufficient potential is developed across electrodes 18 and 20, the pump 82 commences operation to pump any remaining hydrogen being developed in sub-container 96 and air into the fuel cell. Once the pump commences operation, valve 100 is turned to direct the flow of hydrogen/water vapor through line 104 and then into the respective canister 88 and 90. The hot

hydrogen, as it exits from the hydrogen storage system, commences heating of the fuel cell until steady-state temperatures are achieved which are approximately 80°C for the fuel cell and released hydrogen at a temperature in the range of 150°C. With suitable insulation on the enclosure 12, even at -40°C ambient temperatures, steady-state operation maintains the desired temperatures for the hydrogen stream and the fuel cell.

As the hydrogen/water vapor stream circulates through the start-up system 54, any remaining water and glycol is removed. It has been found that the presence of ethylene glycol does not hamper the operation of the fuel cell or the hydride; however, should it have any impact, it is appreciated, of course, that the ethylene glycol can be removed from the hydrogen/water vapor stream before entry into either of the hydride canisters 88 or 90. As is appreciated with the hydride canisters, the sub-container 96 has a membrane separating the aqueous solution from the hydride so that upon actuation of valve 132, the rate at which the water contacts the hydride is controlled by the membrane.

Should it be desired or required to expedite the heating of the fuel cell, it is appreciated that the partition 24 may be withdrawn from the enclosure to allow heat generated at the hydride storage canister to warm up the adjacent fuel cell 30.

Under steady-state conditions, the fuel cell and hydride storage canisters operate in the manner that the cycle of release of hydrogen from the canister, consumption of hydrogen at the anode and recirculation of the hydrogen/water vapor to produce additional hydrogen, uses all of the water vapor at the anode so that water vapor need not be removed from the system. It is appreciated though that some water vapor may be lost at the cathode by virtue of circulation of the air. To compensate for this loss, extra moisture or water may be provided in the sub-container 94 so that during start-up

extra water is available which throughout the operation of the system is slowly taken up by the hydrogen/water vapor stream as it flows therethrough.

This system may be readily provided in a portable and compact form. The total weight of the power supply for 24 hours of operation with a calcium hydride storage is in the range of 4.5 kilograms, or with lithium aluminum hydride storage is in the range of 3.42 kilograms.

Although preferred embodiments of the invention are described herein in detail, it will be understood by those skilled in the art that variations may be made thereto without departing from the spirit of the invention or the scope of the appended claims.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. In a power supply having:

a) an alkaline fuel cell,

b) a hydrogen storage system,

c) means for pumping released hydrogen from an outlet of said hydrogen storage system to a hydrogen inlet for said fuel cell,

d) a source of oxygen, and

e) means for pumping oxygen from said oxygen source to an oxygen inlet for said fuel cell, and the improvement comprising:

i) said hydrogen storage system including a solid chemical hydride for storing hydrogen in a chemically bound form, said chemical hydride releasing hydrogen gas when contacted by and reacted with water molecules, said storage system having an outlet connected to said hydrogen pumping means; and

ii) said fuel cell having said hydrogen inlet connected to said hydrogen pumping means and an outlet for exhausting excess hydrogen from said fuel cell, means for passing hydrogen from said fuel cell hydrogen inlet over said anode to react at said anode and vaporize water produced at said anode during operation of said power supply to form thereby a hydrogen/water vapor mixture exhausted at said fuel cell outlet, means for recirculating exhausted hydrogen/water vapor mixture from said fuel cell outlet to an inlet of said hydrogen storage system to reintroduce thereby water molecules to said chemical hydride to release additional hydrogen gas at said outlet of said hydrogen storage system.

2. In a power supply of claim 1,

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i) means for releasably connecting said outlet of said hydrogen storage system to said hydrogen pumping means,

ii) means for releasably connecting said inlet of said hydrogen storage system to said recirculating means,

iii) an enclosure for said system being adapted to permit access to said hydrogen storage system for replacement thereof by a fresh hydrogen storage system.

3. In a power supply of claim 1 both of said hydrogen pumping means and said oxygen pumping means being electrically powered by electrical energy generated by said fuel cell.

4. In a power supply of claim 1, said source of oxygen being air, said oxygen pumping means pumping air through means for removing carbon dioxide from air prior to entry of air through said fuel cell oxygen inlet.

5. In a power supply of claim 4, said means for removing carbon dioxide being a disposable canister of granular material which removes carbon dioxide from air.

6. In a power supply of claim 1, means for starting said power supply, said starting means comprising means for storing water and means for introducing water molecules from said water storing means into said hydrogen storage means when it is desired to start said power supply.

7. In a power supply of claim 1, said hydrogen pumping means and said oxygen pumping means being driven by a common electrically powered motor.

8. In a power supply of claim 1, said solid chemical hydride is selected from the group consisting of calcium hydride and lithium aluminum hydride.

9. In a power supply of claim 8, said selected solid chemical hydride is in granular form.

10. A hydrogen storage system for use in a portable power supply using an alkaline fuel cell which requires hydrogen for power generation, said hydrogen storage system comprising:

i) a container having an inlet and an outlet, each with means for releasable connection to hydrogen transport tubing,

ii) a granular solid chemical hydride for storing hydrogen in a chemically bound form, said hydride being stored in said container with a water vapor membrane isolating said chemical hydride from said inlet;

iii) said container inlet directing hydrogen and entrained water vapor through said granular hydride to produce hydrogen which is exhausted through said outlet.

11. A hydrogen storage system of claim 10 wherein said container includes means for starting release of hydrogen from stored hydride, said starting means comprising:

i) a sub-container of water,

ii) means for introducing water from said sub-container to said container to release hydrogen at said outlet.

12. A hydrogen storage system of claim 10 wherein said container includes means for starting release of hydrogen from stored hydride, said starting means comprising:

i) a first sub-container of water;

ii) a second sub-container of granular hydride;

iii) means for introducing water molecules from said first sub-container to said second sub-container to release hydrogen from said second sub-container, said second sub-container being connected to said container outlet.

13. A process for generating power in an alkaline fuel cell which requires hydrogen at its anode and oxygen at its cathode during power generation, said process comprising:

i) storing hydrogen in a chemically bound form as a solid granular chemical hydride, said chemical hydride releasing hydrogen when contacted by and reacted with water molecules,

ii) pumping released hydrogen from said storage to said fuel cell and passing hydrogen over said anode of said fuel cell to develop power when oxygen is present at said cathode where water vapor is produced at said anode during power generation,

iii) an excess of hydrogen being pumped through said fuel cell as generated by reaction of water molecules with said hydride, said water vapor in said cell vaporizing in said flow of hydrogen to form a hydrogen/water vapor mixture;

iv) recirculating said hydrogen/water vapor mixture to said hydrogen storage whereby water molecules of said water vapor reacts with said hydride to release more hydrogen which is pumped to said fuel cell;

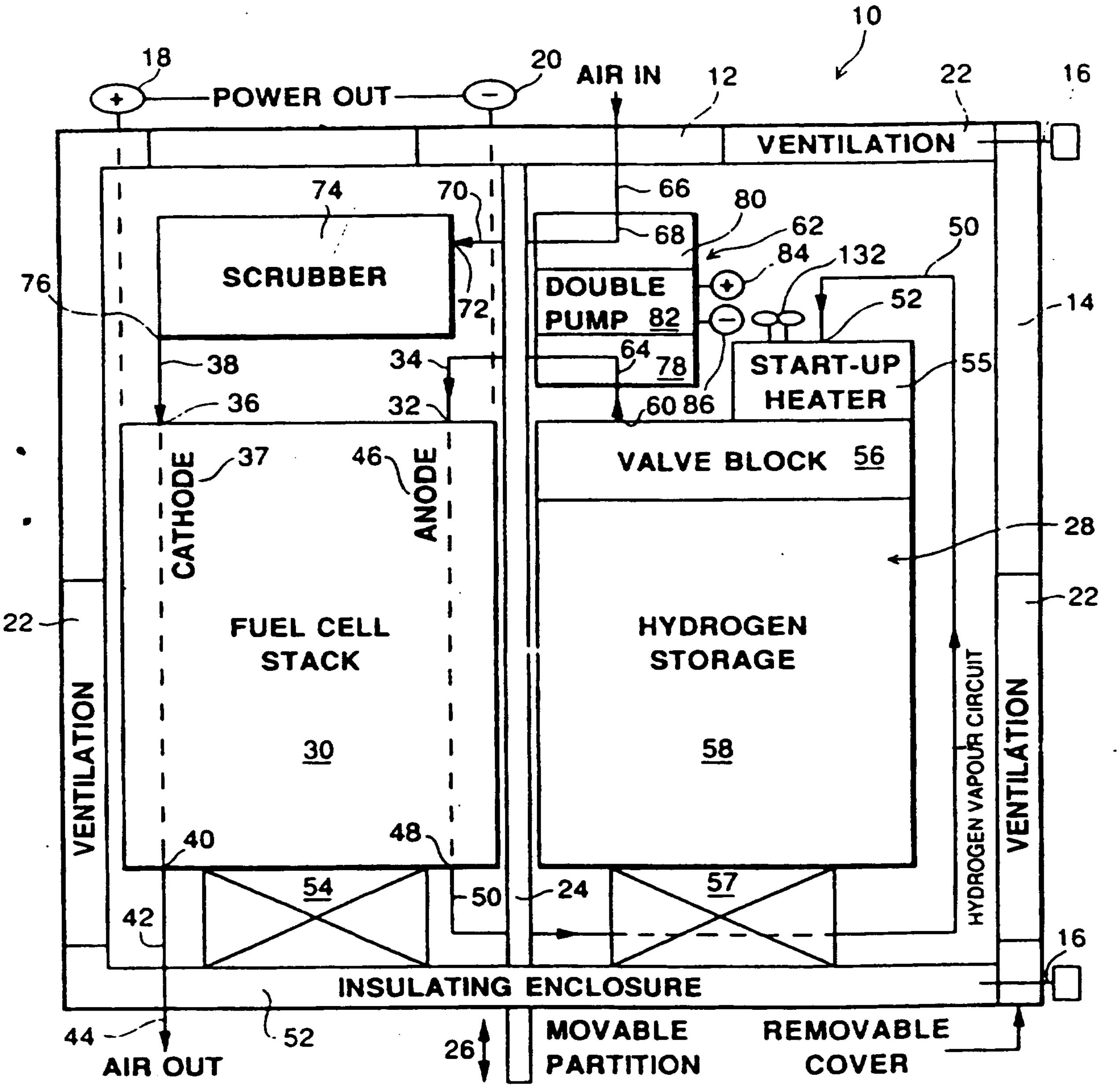
v) during power demand, said hydrogen/water vapor mixture being continuously recirculated whereby all water vapor produced at said anode is recirculated and reacted with said chemical hydride to maintain a steady state operation of a cycle of hydrogen release, hydrogen consumption at said fuel cell anode and production of water vapor at said fuel cell anode for further generation of hydrogen.

14. A process of claim 13 wherein said chemical hydride is selected from the group consisting of calcium hydride and lithium aluminum hydride.

15. A process of claim 13 wherein during start-up of said fuel cell, excess water is added to said chemical

hydride to produce sufficient hydrogen to achieve said steady state of operation of said cycle.

FIG. 1


10
18
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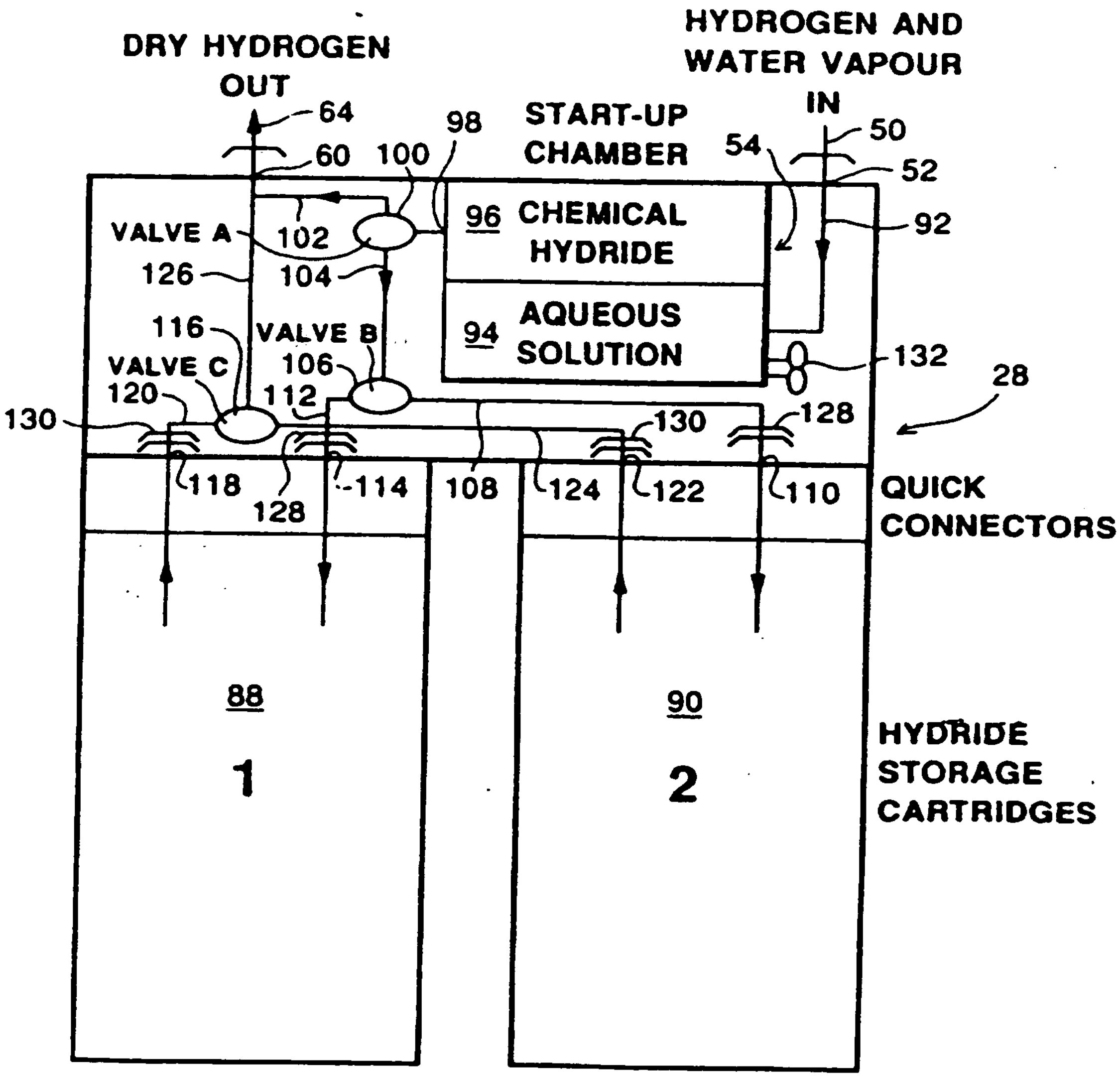
POWER OUT
AIR IN
12
22
16
VENTILATION
74
70
66
80
68
62
84
132
50
SCRUBBER
DOUBLE
PUMP 82
52
14
76
72
38
34
64
78
START-UP
HEATER
55
36
32
60 86
VALVE BLOCK 56
37
46
CATHODE
ANODE
28
FUEL CELL
STACK
30
HYDROGEN
STORAGE
58
22
VENTILATION
HYDROGEN VAPOUR CIRCUIT
VENTILATION
40
48
54
50
24
57
42
16
INSULATING ENCLOSURE
44
52
26
AIR OUT
MOVABLE
PARTITION
REMOVABLE
COVER

FIG. 2



DRY HYDROGEN OUT
HYDROGEN AND WATER VAPOUR IN
START-UP CHAMBER
96 CHEMICAL HYDRIDE
94 AQUEOUS SOLUTION
VALVE A
VALVE B
VALVE C
64
60
98
100
102
104
106
108
110
112
114
116
118
120
122
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130
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54
92
28
QUICK CONNECTORS
88
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2
HYDRIDE STORAGE CARTRIDGES

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